Quantum Dot Vertical Cavity Surface Emitting

Inventors: Xiaodong Huang et al. Docket No.: 22920-06460

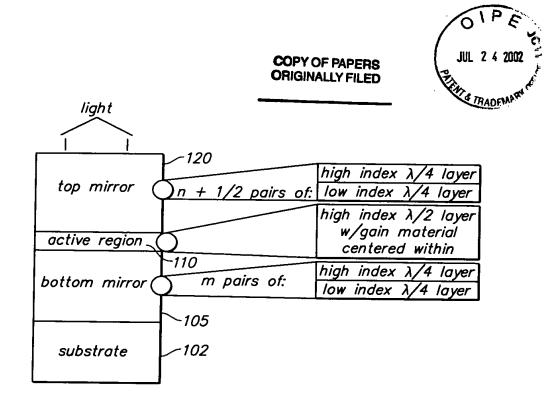


FIG. 1 (PRIOR ART)

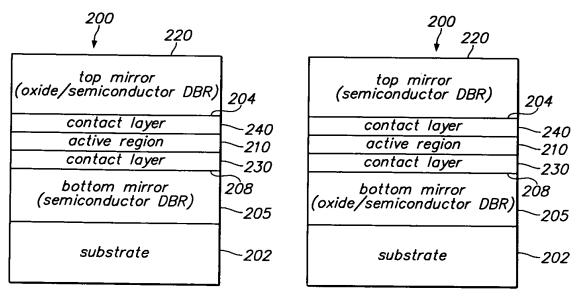
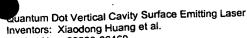
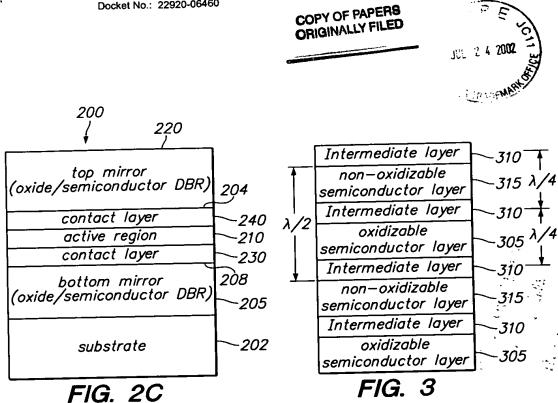
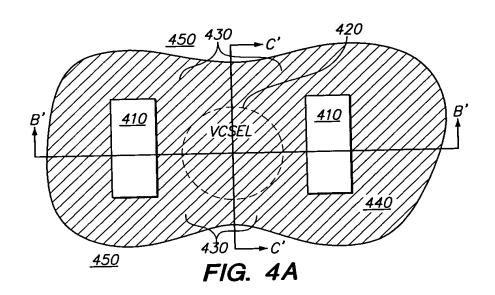


FIG. 2A

FIG. 2B







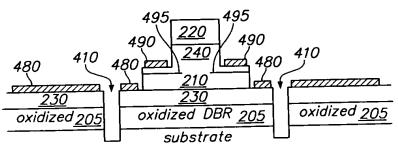


FIG. 4B

Quantum Dot Vertical Cavity Surface Emitting Inventors: Xiaodong Huang et al.

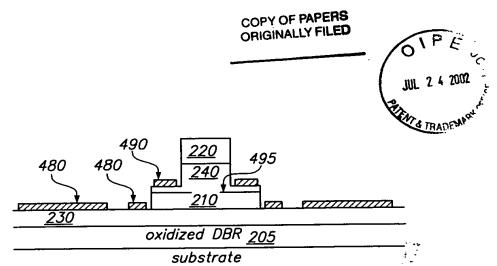


FIG. 4C

$$240 \begin{cases} \hline Top \ DBR \ mirror & \underline{220} \\ \hline p+-GaAs \ \underline{505} & & & & & & \\ \hline p-GaAs & \underline{510} & & & & \\ \hline AlGaAs \ current \ aperture \ layer \ \underline{515} & & & & \\ \hline mode \ control \ layers & & \underline{210} \\ active \ region & & & & \\ \hline 230 \begin{cases} \hline AlGaAs \ current \ aperture \ layer \ \underline{545} \\ \hline n+ \ GaAs \ \underline{540} & & & & \\ \hline Bottom \ DBR \ mirror & \underline{205} \\ substrate & & \underline{202} \end{cases}$$

FIG. 5A

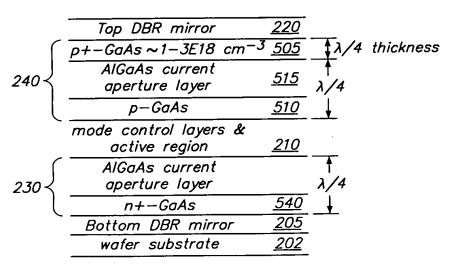


FIG. 5B





	top DBR mirror -	-220
λ/2	p-type contact layer	.)
1/2	top current aperture layer	>240
λ/4	mode control layers	602
. —	active region including QD's -	210
λ/4	mode control layers	604
2/2	bottom current aperture layer	610
~/~ <u>+</u>	n-type contact layer	≥230
	Bottom DBR mirror -	205
	substrate	-202

FIG. 6A

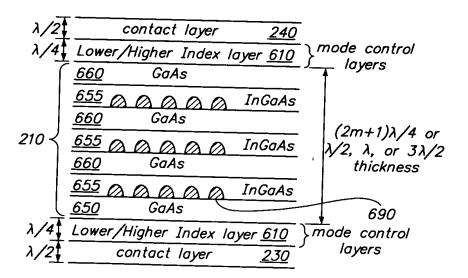


FIG. 6B

Quantum Dot Vertical Cavity Surface Emitting Lever Inventors: Xiaodong Huang et al. Docket No.: 22920-06460

)																		-	OPIO ORIO	SIN 	OF P	YF	ERS	3 D	-	U.	T 2 h
				p-contact	Mode Control	p-contact	Current aperture	grade for current aperture	Active	600°C Active	Active	Active	Active	510°C Active	Active	Mode Control	n-contact					£ 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	200			1 miles	
gznm, ox	10nm, 5x	213nm, 5x	10nm, 5x	92nm	p1017 107nm	71nm	p1017 50nm	12nm	20nm	10nm, 3x	0.8nm, 3x	~8nm, 3x	2.4ML, 3x	1nm, 3x	159nm	n1017 107nm	92nm	10nm, 8x	213nm, 8x	10nm, 8x	92nm, 8x	10nm	213nm	10nm	200nm600C		FIG. 7
GAAS	_	_	Aig2GaggAs	GaAs, p318	610 Alg26908As,	GaAs, p117	AlgaGao2As,	A/92Gq08As	GaAs	GoAs	GaAs	210 < In15 Gags As	InAs	In 15 Gags As	GaAs	610 Alg2Gagas,	230 GaAs, n218	<u> </u>	AIAS	$\overline{}$	_	Alg2Gq08As	AIAS	Alg2Ga08As	GOAS	GaAs N+2" 1-side	
	9Znm,	GOAS A/92GQ08AS		4/92Gq08As 3Znm, A/92Gq08As 10nm, A/92Gq08As 10nm,	GGAS 92nm, 5x Alg2GggAs 10nm, 5x AlAs 213nm, 5x Alg2GggAs 10nm, 5x GGAs, p318 92nm	GOAS 92nm, 5x 4!92G908As 10nm, 5x AIAS 213nm, 5x A!92G908As 10nm, 5x GOAs, p318 92nm A!92G908As, p1017 107nm	GGAS 92nm, 5x A!g2Gqg8As 10nm, 5x A!As 213nm, 5x A!g2Gqg8As 10nm, 5x GGAs, p318 92nm A!g2Gqg8As, p1017 71nm	GAAS 92nm, 5x 4!g2Ga0gAs 10nm, 5x 4!AS 213nm, 5x A!g2Ga0gAs 10nm, 5x GaAs, p3!8 92nm 4!g2Ga0gAs, p10? 71nm GaAs, p11? 71nm A!ggGa0zAs, p10? 50nm	GaAs 92nm, 5x 4!g2Gq0gAs 10nm, 5x A!As 213nm, 5x A!g2Gq0gAs 10nm, 5x GaAs, p318 92nm p-contact A!g2Gq0gAs, p10 17 107nm Mode Control GaAs, p117 71nm p-contact A!ggGq0zAs, p10 17 50nm Current aperture A!ggGq0gAs 12nm grade for current	GaAs 92nm, 5x 4!g2Ga0gAs 10nm, 5x 4!As 213nm, 5x 4!g2Ga0gAs 10nm, 5x GaAs, p3!8 92nm p-contact 4!g2Ga0gAs, p1o17 107nm Mode Control GaAs, p1!7 71nm p-contact A!ggGa0gAs p1o17 50nm Current aperture A!ggGa0gAs 12nm grade for current GaAs 20nm Active	GAAS 92nm, 5x 4!92Gq08As 10nm, 5x AIAS 213nm, 5x AIg2Gq08As 10nm, 5x GAS, p318 92nm p-contact A!92Gq08As p1o17 107nm Mode Control GAS, p117 71nm p-contact A!98Gq02As p1o17 50nm Current aperture A!92Gq08As 12nm 4ctive GAS 10nm, 3x 600°C Active	GAAS 92nm, 5x 4!92G908As 10nm, 5x A!AS 213nm, 5x A!92G908As 10nm, 5x GAS, p318 92nm p-contact GAS, p117 71nm p-contact A!92G908As p1o17 50nm p-contact A!92G908As 12nm p-contact A!92G908As 12nm Active GAS 20nm Active GAS 10nm, 3x 600°C Active GAS 0.8nm, 3x Active	GOAS $9Znm$, $5x$ $4lg2Gqg8AS$ $10nm$, $5x$ $AlAS$ $213nm$, $5x$ $AlAS$ $213nm$, $5x$ $Alg2Gqg8AS$ $10nm$, $5x$ $Alg2Gqg8AS$ $9Znm$ $p-contact$ $Alg2Gqg8AS$ $p1o17$ $107nm$ $Mode$ Control $CaAs$, $p117$ $7lnm$ $p-contact$ $Alg2GqgAS$ $p1o17$ $50nm$ $p-contact$ $Alg2GqgAS$ $12nm$ $qrade$ for current $GaAS$ $20nm$ $Active$ $GaAS$ $10nm$, $3x$ $600^{\circ}C$ $Active$ $GaAS$ $0.8nm$, $3x$ $Active$ $In_{15}GqgSAS$ $\sim 8nm$, $3x$ $Active$	GAAS $92nm$, $5x$ $4lg2GggAS$ $10nm$, $5x$ $4lAS$ $213nm$, $5x$ $4lAS$ $213nm$, $5x$ $4lg2GggAS$ $10nm$, $5x$ $GaAs$, $p318$ $92nm$ $p-contact$ $4lg2GggAS$ $p1o17$ $107nm$ $Mode$ Control $GaAs$, $p117$ $71nm$ $p-contact$ $Alg2GggAS$ $p1o17$ $50nm$ $p-contact$ $Alg2GggAS$ $12nm$ $qrade$ for current $GaAS$ $20nm$ $Active$ $GaAS$ $10nm$, $3x$ $600^{\circ}C$ $Active$ $GaAS$ $0.8nm$, $3x$ $Active$ $In15GgSAS$ $\sim 8nm$, $3x$ $Active$ $InAS$ $2.4ML$, $3x$ $Active$	GOAS $920m$, $5x$ $4lg2GggAS$ $10nm$, $5x$ $AlAS$ $213nm$, $5x$ $AlAS$ $213nm$, $5x$ $Alg2GggAS$ $10nm$, $5x$ $GaAs$, $p318$ $92nm$ $p-contact$ $GaAs$, $p117$ $71nm$ $p-contact$ $Alg2GggAS$ $p1o17$ $50nm$ $p-contact$ $Alg2GggAS$ $12nm$ $p-contact$ $Alg2GggAS$ $12nm$ $p-contact$ $Alg2GggAS$ $12nm$ $p-contact$ $Alg2GggAS$ $10nm$, $3x$ $active$ $GaAS$ $active$ $active$ $Alg2GggSAS$ $active$ $active$ $AlgSGgSAS$ $active$ Al	GOAS92nm, $3x$ 4 $lg2Gag8As$ $10nm, 5x$ AlAs $213nm, 5x$ AlAs $213nm, 5x$ Alg2Gag8As $10nm, 5x$ GoAs, $p318$ $92nm$ $p-contact$ Alg2Gag8As $p1o17$ $107nm$ $p-contact$ Alg2Gag8As $p1o17$ $50nm$ $p-contact$ Alg2Gag8As $12nm$ $qrade$ for currentGaAs $10nm, 3x$ $600C$ $Active$ GaAs $0.8nm, 3x$ $Active$ In15 GagsAs $2.4ML, 3x$ $Active$ In15 GagsAs $1nm, 3x$ $Active$	GaAs $Aig2GaggAs$ $AigaGaggAs$ $AigaGAGAS$ $Aiga$	GaAs $92nm$, $5x$ $4lg_2Gg_0gAs$ $10nm$, $5x$ Alg_2Gg_0gAs $213nm$, $5x$ Alg_2Gg_0gAs $10nm$, $5x$ Alg_2Gg_0gAs $92nm$ $p-contact$ Alg_2Gg_0gAs $p1o^{17}$ $107nm$ $p-contact$ Alg_2Gg_0gAs $p1o^{17}$ $50nm$ $p-contact$ Alg_2Gg_0gAs $12nm$ $p-contact$ Alg_2Gg_0gAs $12nm$ $p-contact$ Alg_2Gg_0gAs $12nm$ $Active$ $GaAs$ $10nm$, $3x$ $Active$ $GaAs$ $0.8nm$, $3x$ $Active$ $Infs$ GagsAs Inm , $3x$ $Active$ $Infs$ GagsAs Inm , $3x$ $Active$ $GaAs$ Inm , $3x$ $Active$ $Infs$ GagsAs Inm , $3x$ $Active$ $GaAs$ $Infs$ GagsAs $Infs$ GagsAs Alg_2Gg_0gAs $Infs$ GagAs $Infs$ GagAs Alg_2Gg_0gAs $Infs$ GagAs $Infs$ GagAs $Infs$ GagAs	GAAS 92nm, 3x Alg2GagAs 10nm, 5x AlAS 213nm, 5x AlAS 213nm, 5x Alg2GagAs 10nm, 5x GAS, p318 92nm p-contact Alg2GagAs, p1017 107nm Mode Control GAS, p117 71nm p-contact Alg2GagAs, p1017 50nm Current aperture GAS, p117 71nm Active Alg2GagAs 10nm, 3x 600°C GAS 0.8nm, 3x Active Ints 2.4ML, 3x Active Ints 2.4ML, 3x Active Ints 500°C Active Ints 500°C Active GAS 100°C Active Ints 500°C Active GAS 100°C Active GAS 100°C Active GAS 100°C Active Alg2GagAS 100°C Active Alg2GagAS 100°C Active Alg2GagAS 100°C	GGAS 92nm, 3x Alg2GagAS 10nm, 5x AlAS 213nm, 5x Alg2GagAS 10nm, 5x Alg2GagAS 10nm, 5x GoAS, p318 92nm p-contact Alg2GagAS, p1o17 107nm Mode Control GoAS, p117 71nm p-contact Alg2GagAS, p1o17 50nm Current aperture GoAS 12nm Active GaAS 10nm, 3x 600°C Active GaAS 10nm, 3x Active Inj5GagSAS 10nm, 3x Active Inj5GagSAS 1nm, 3x Active Inj5GagAS 1nm, 3x Active GoAS 1nm, 3x 510°C Active Inj5GagAS 1nm, 3x Active GoAS 1nm, 3x 510°C Active GoAS 10nm, 3x Active GoAS 10nm, 8x n-contact AlaS 213nm, 8x n-contact	Alg2GggAs 92nm, 5x Alg2GggAs 10nm, 5x Alg2GggAs 213nm, 5x Alg2GggAs 10nm, 5x GoAs, p318 92nm Alg2GggAs 10nm, 5x Alg2GggAs 107nm Alg2GggAs 12nm Alg2GggAs 12nm Alg2GggAs 10nm, 3x GoAs 10nm, 3x GoAs 0.8nm, 3x Active 0.8nm, 3x Alg2GggAs 10nm, 8x Alg2CiggAs 10nm, 8x <td>GOAS 92nm, 3x Alg2GogAs 10nm, 5x AlAs 213nm, 5x Alg2GogAs 10nm, 5x GoAs, p318 92nm p-contact Alg2GogAs 10nm, 10017 107nm Alg2GogAs p1017 107nm Alg2GogAs p1017 50nm Alg2GogAs 12nm grade for current aperture GoAs 12nm Active GoAs 10nm, 3x 600°C GoAs 10nm, 3x Active GoAs 0.8nm, 3x Active GoAs 0.8nm, 3x Active GoAs 10nm, 3x Active GoAs 10nm, 3x Active GoAs 10nm, 3x Active GoAs 10nm, 8x Active Alg2GogAs 10nm, 8x Active Alg2GogAs 10nm, 8x Active Alg2GogAs 10nm, 8x Active</td> <td>GOAS 92nm, 3x $Alg2G0gAs$ $10nm$, $5x$ $Alg2G0gAs$ $10nm$, $5x$ $Alg2G0gAs$ $10nm$, $5x$ $GoAs$, $p318$ $92nm$ $p-contact$ $GoAs$, $p318$ $92nm$ $p-contact$ $GoAs$, $p17$ $107m$ $p-contact$ $GoAs$, $p17$ $71nm$ $p-contact$ $GoAs$, $p17$ $71nm$ $p-contact$ $GoAs$ $12nm$ $q-contact$ $GoAs$ $12nm$ $Active$ $GoAs$ $10nm$, $3x$ $Active$ $GoAs$ $159m$ $Active$ $Alg2GogAs$ $10nm$, $8x$ $n-contact$ $AllAs$ $213m$, $8x$ $n-contact$ $AllAs$ $10nm$, $8x$ $n-contact$ $AllAs$ $10nm$, $8x$ $accolor occolor occolor occolor occolor occolor occolor oc$</td> <td>AlggoggAs 10nm, 5x AlggoggAs 10nm, 5x AlgsoggAs 1017 107nm Mode Control GoAs, p318 92nm P-contact AlgsoggAs 12nm Qurent aperture GoAs 20nm Active GoAs 20nm Active GoAs 0.8mm, 3x Active Ints GggAs 10mm, 3x Active GoAs 10mm, 3x Active AlgsoggAs 10nm, 3x Active AlgsoggAs 10nm, 3x Active AlgsoggAs 10nm, 8x Active Alas 10nm, 8x Active Al</td> <td>GAAS 92nm, 3x 4/92G9084S 10nm, 5x AlAS 213nm, 5x AlAS 213nm, 5x Alg2G9084S 10nm, 5x GoAs, p318 92nm p-contact GoAs, p117 71nm p-contact Alg2G9084S, p1017 107nm Mode Control GoAs 12nm p-contact Alg2G9084S 12nm Active GAS 10nm, 3x Active In15G9SAS 10mm, 3x Active In15G9SAS 1nm, 3x Active In15G9SAS 1nm, 3x Active In15G9SAS 10mm, 8x Active Alg2G908AS 10mm, 8x Active Alg2G908AS 10mm, 8x Active Alg2G908AS 10mm, 8x Alg2G908AS Alg2G908AS 10mm, 8x Alg2G908AS 10mm, 8x Alg2G908AS 10mm, 8x Alg2G908AS 10mm</td> <td>AlggGggAs 10nm, 5x AlggCgggAs 10nm AlggCgggAs 1017 107nm AlggCgggAs 10nm, 3x 600°C AlggCgggAs 10nm, 3x Active GaAs 10nm, 3x Active Injs GggSAs 24ML, 3x Active Injs GggAs 10nm, 8x Active AlggCqggAs 10nm, 8x Active AlggCqggAs 10nm, 8x Active AlggCqgAs 10nm, 8x Active AlggCqggAs 10nm Active AlggCqgAs 10nm Active Alg</td> <td>Gods 92nm, 3x Alg2GagAs 10nm, 5x Alg2GagAs 10nm Alg2GagAs 1017 107nm Alg2GagAs 10nm, 3x 600°C Alg2GagAs 10nm, 3x Active GaAs 10nm, 3x Active GaAs 10nm, 3x Active In15 GagSAs 10nm, 3x Active In45 GagSAs 10nm, 8x Active Alg2GagAs 10nm Active Alg2GagAs</td>	GOAS 92nm, 3x Alg2GogAs 10nm, 5x AlAs 213nm, 5x Alg2GogAs 10nm, 5x GoAs, p318 92nm p-contact Alg2GogAs 10nm, 10017 107nm Alg2GogAs p1017 107nm Alg2GogAs p1017 50nm Alg2GogAs 12nm grade for current aperture GoAs 12nm Active GoAs 10nm, 3x 600°C GoAs 10nm, 3x Active GoAs 0.8nm, 3x Active GoAs 0.8nm, 3x Active GoAs 10nm, 3x Active GoAs 10nm, 3x Active GoAs 10nm, 3x Active GoAs 10nm, 8x Active Alg2GogAs 10nm, 8x Active Alg2GogAs 10nm, 8x Active Alg2GogAs 10nm, 8x Active	GOAS 92nm, 3x $Alg2G0gAs$ $10nm$, $5x$ $Alg2G0gAs$ $10nm$, $5x$ $Alg2G0gAs$ $10nm$, $5x$ $GoAs$, $p318$ $92nm$ $p-contact$ $GoAs$, $p318$ $92nm$ $p-contact$ $GoAs$, $p17$ $107m$ $p-contact$ $GoAs$, $p17$ $71nm$ $p-contact$ $GoAs$, $p17$ $71nm$ $p-contact$ $GoAs$ $12nm$ $q-contact$ $GoAs$ $12nm$ $Active$ $GoAs$ $10nm$, $3x$ $Active$ $GoAs$ $159m$ $Active$ $Alg2GogAs$ $10nm$, $8x$ $n-contact$ $AllAs$ $213m$, $8x$ $n-contact$ $AllAs$ $10nm$, $8x$ $n-contact$ $AllAs$ $10nm$, $8x$ $accolor occolor occolor occolor occolor occolor occolor oc$	AlggoggAs 10nm, 5x AlggoggAs 10nm, 5x AlgsoggAs 1017 107nm Mode Control GoAs, p318 92nm P-contact AlgsoggAs 12nm Qurent aperture GoAs 20nm Active GoAs 20nm Active GoAs 0.8mm, 3x Active Ints GggAs 10mm, 3x Active GoAs 10mm, 3x Active AlgsoggAs 10nm, 3x Active AlgsoggAs 10nm, 3x Active AlgsoggAs 10nm, 8x Active Alas 10nm, 8x Active Al	GAAS 92nm, 3x 4/92G9084S 10nm, 5x AlAS 213nm, 5x AlAS 213nm, 5x Alg2G9084S 10nm, 5x GoAs, p318 92nm p-contact GoAs, p117 71nm p-contact Alg2G9084S, p1017 107nm Mode Control GoAs 12nm p-contact Alg2G9084S 12nm Active GAS 10nm, 3x Active In15G9SAS 10mm, 3x Active In15G9SAS 1nm, 3x Active In15G9SAS 1nm, 3x Active In15G9SAS 10mm, 8x Active Alg2G908AS 10mm, 8x Active Alg2G908AS 10mm, 8x Active Alg2G908AS 10mm, 8x Alg2G908AS Alg2G908AS 10mm, 8x Alg2G908AS 10mm, 8x Alg2G908AS 10mm, 8x Alg2G908AS 10mm	AlggGggAs 10nm, 5x AlggCgggAs 10nm AlggCgggAs 1017 107nm AlggCgggAs 10nm, 3x 600°C AlggCgggAs 10nm, 3x Active GaAs 10nm, 3x Active Injs GggSAs 24ML, 3x Active Injs GggAs 10nm, 8x Active AlggCqggAs 10nm, 8x Active AlggCqggAs 10nm, 8x Active AlggCqgAs 10nm, 8x Active AlggCqggAs 10nm Active AlggCqgAs 10nm Active Alg	Gods 92nm, 3x Alg2GagAs 10nm, 5x Alg2GagAs 10nm Alg2GagAs 1017 107nm Alg2GagAs 10nm, 3x 600°C Alg2GagAs 10nm, 3x Active GaAs 10nm, 3x Active GaAs 10nm, 3x Active In15 GagSAs 10nm, 3x Active In45 GagSAs 10nm, 8x Active Alg2GagAs 10nm Active Alg2GagAs

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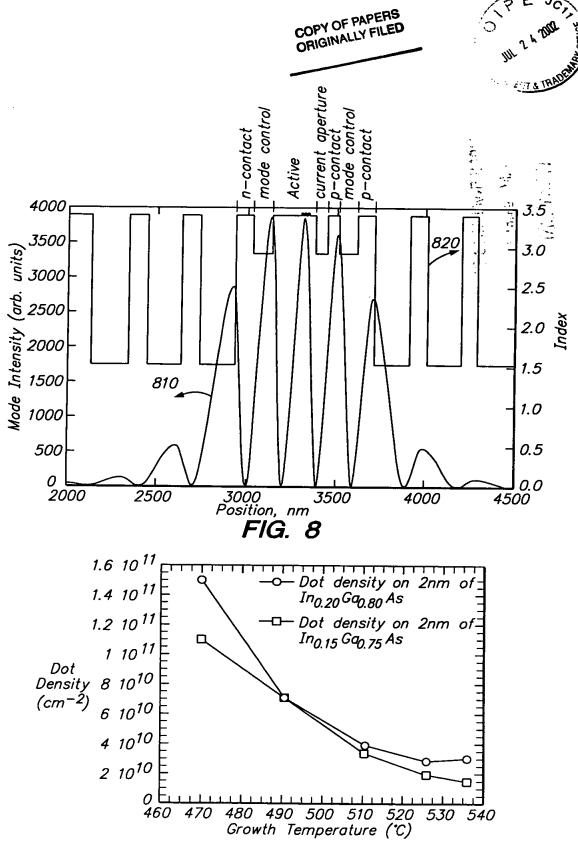
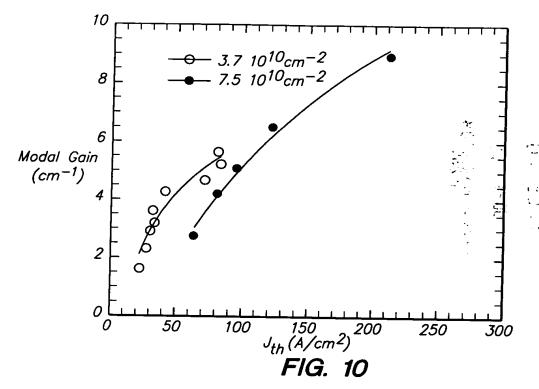


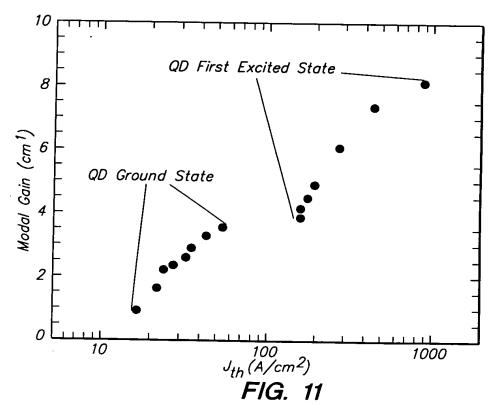
FIG. 9

Quantum Dot Vertical Cavity Surface Emitting Laser Inventors: Xiaodong Huang et al. Docket No.: 22920-06460









Quantum Dot Vertical Cavity Surface Emitting Leser Inventors: Xiaodong Huang et al.

Docket No.: 22920-06460

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FIG. 12A

	<u>1220</u>	
1215	InGaAs 6-11nm (460-490°C)	
1205~In	As 1-3 monolayers (470-540° InGaAs 0.5-2nm (~490°C)	<u>c)</u>
_	GaAs	
		1220

FIG. 12B

	top mirror	
	contact layer	210
† }	active region & mode control QD	mode
1		∫ 1305
	contact layer	$\overline{\exists}$
	bottom mirror	230
	substrate	
	FIG. 13	202

Quantum Dot Vertical Cavity Surface Emitting Laser Inventors: Xiaodong Huang et al. Docket No.: 22920-06460





	top mirror	<u>220</u>	<u> </u>
	contact layers	240	14,10
† 2λ	active region &	,	420
1	mode control	}	420
	contact layers	<u>230</u>	-
	bottom mirror	<u>205</u>	
	wafer substrate	<u>202</u>	

FIG. 14

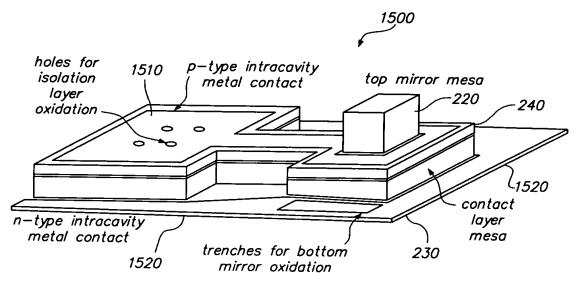


FIG. 15A

Quantum Dot Vertical Cavity Surface Emitting Laser Inventors: Xiaodong Huang et al. Docket No.: 22920-06460





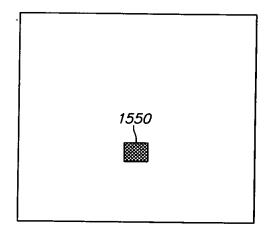
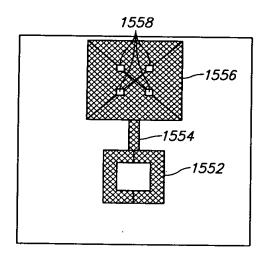




FIG. 15B



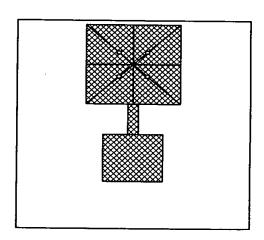
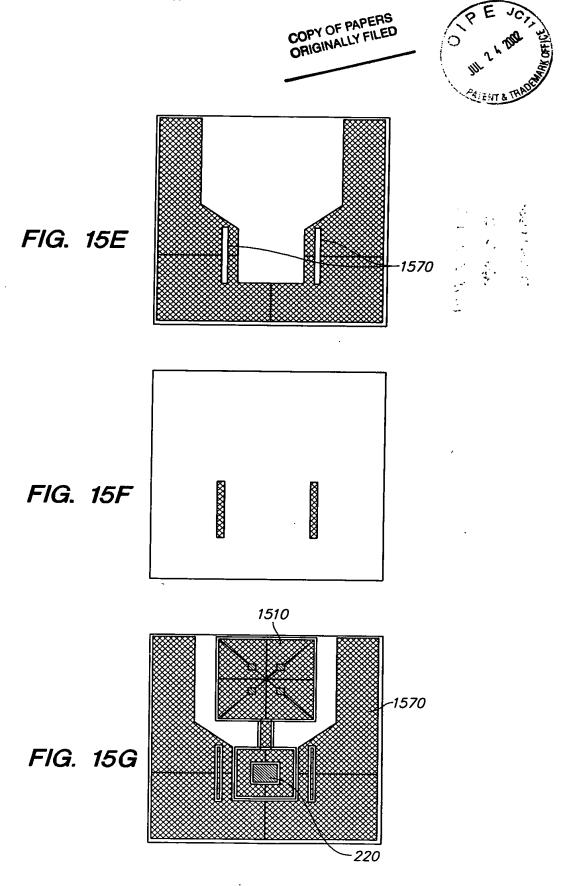


FIG. 15C

FIG. 15D



vantum Dot Vertical Cavity Surface Emitting Laser Ventors: Xiaodong Huang et al. Docket No.: 22920-06460





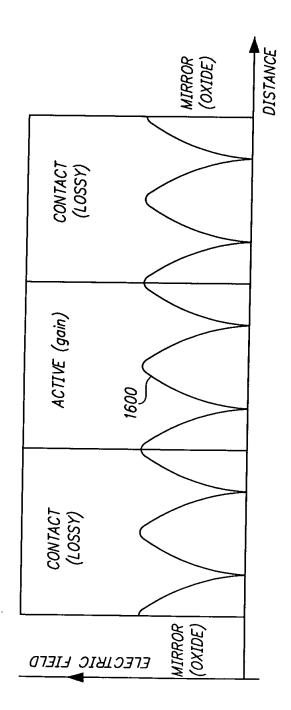


FIG. 16A

